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## (54) Heat transfer panel

(57) A thermal management system using heat pipe principles and incorporating capillary-pumped equipment mounting panels such that a heat transport loop without moving parts is provided. The panels can function to either absorb heat or to reject heat and can interface with heat generating equipment or heat radiators. Each panel comprises a pair of coextensive flat plates bonded together with a thin, fine-pore sheet wick interposed therebetween. A network of liquid grooves in one plate is in fluid communication with the sheet wick which covers the grooves and most of the plate and a separate liquid line connecting the panels. A network of vapor channels in the other plate is in fluid communication with the wick and with a separate vapor line connecting the panels. The vapor channel networks of the panels and the liquid groove networks of the panels are connected such that the panels are arranged in parallel in the fluid circuit or loop. A heat input into panels in the loop causes evaporation of liquid off the surface of the sheet wick. Vapor from the evaporated liquid is circulated to panels serving as cold sinks where the vapor is condensed. Capillary action of the wicks returns the condensate to the panels being heated where the cycle is repeated.

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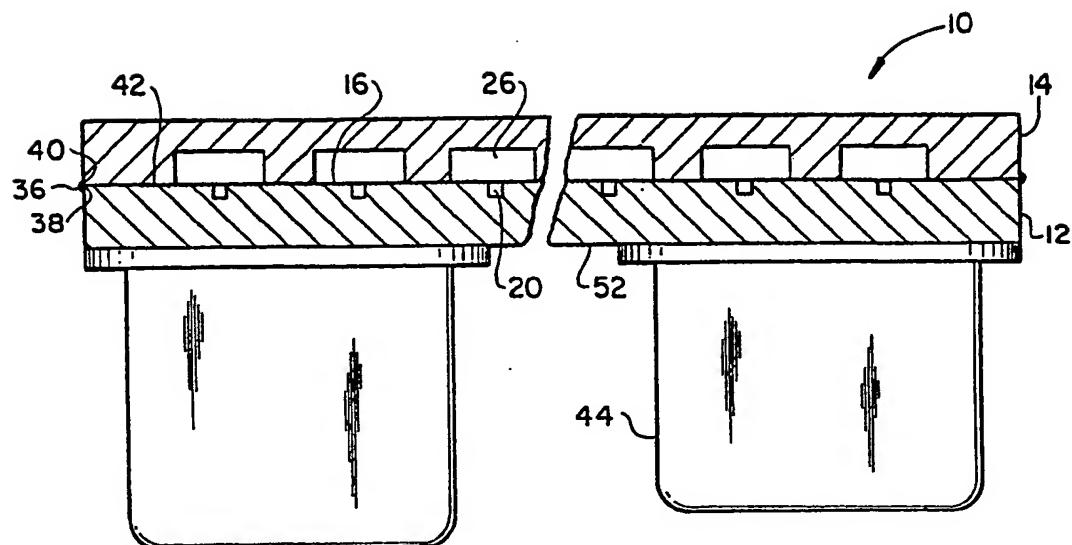


FIG. 1

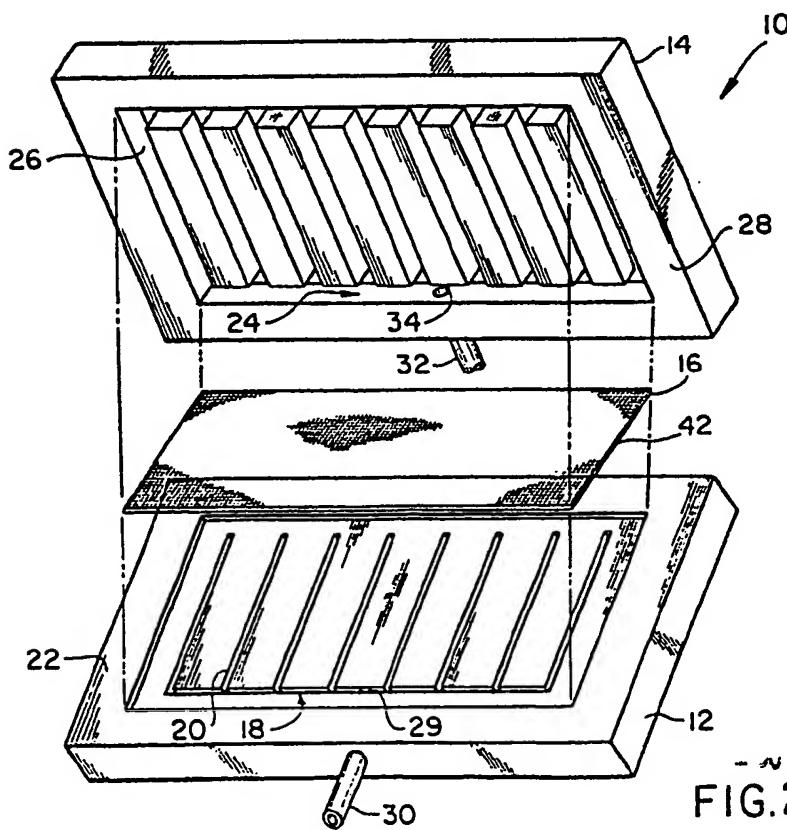


FIG. 2

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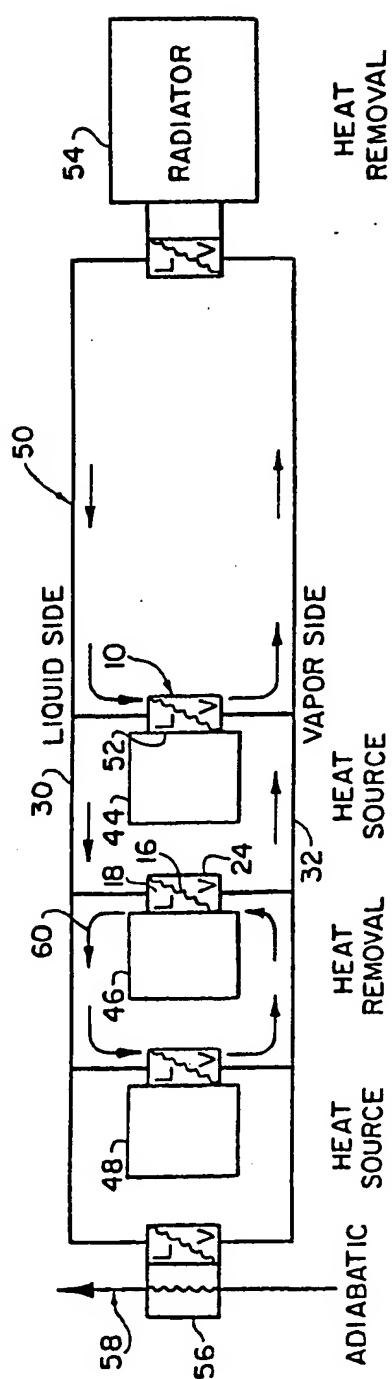


FIG. 3

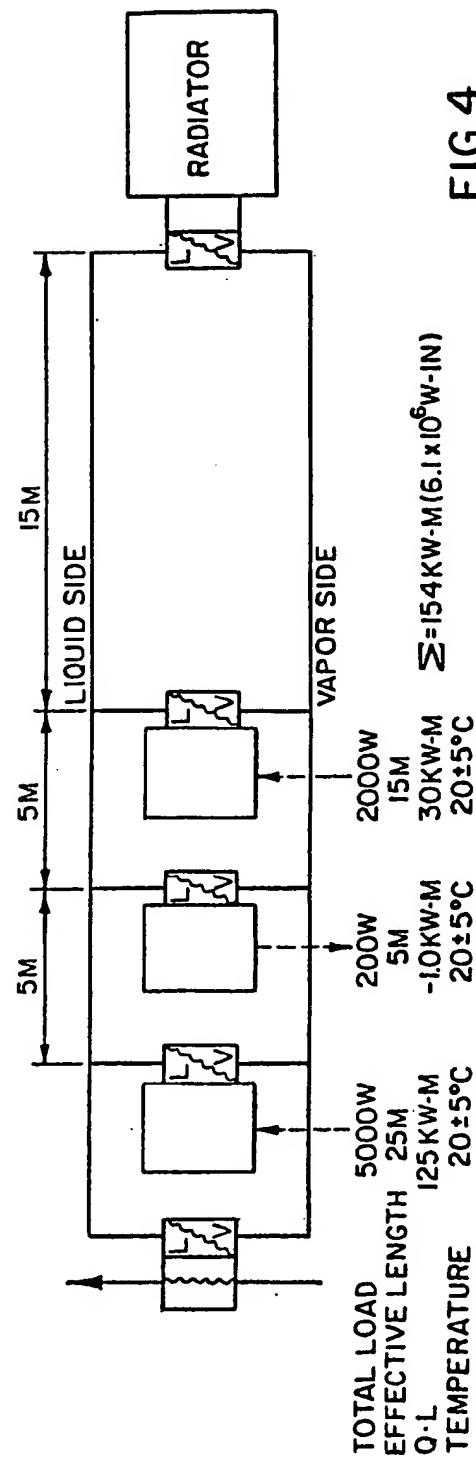


FIG. 4

## SPECIFICATION

## Capillary-pumped heat transfer panel &amp; system

5 This invention relates to thermal management systems and, in particular, to a two-phase heat transfer system using heat pipe principles and to capillary-pumped equipment mounting 10 panels employed therewith.

In current space activities, the very large, longlife space systems presently being planned are based on the large lift capabilities of the United States Space Shuttle. These 15 large satellites and other space projects will require thermal management systems with multikilowatt capacity capable of collecting and transporting heat from various subsystems to heat rejection radiators. Transport distances 20 are expected to be on the order of 10 to 30 meters. Current technology for large thermal transport systems is based on circulating liquid loops. These tend to be heavy and vulnerable to micrometeoroid puncture, have relatively 25 low thermal performance (film coefficients), and require significant amounts of pump power. As current demonstrated pump life is only 2-1/2 years, the pumps and the required valves also lower system reliability. Many 30 problems inherent in thermal systems using a circulating liquid can be alleviated by using a capillary-pumped two-phase circulating system. Liquid delivered to the mounting panels on which heat generating equipment is fixed 35 would pick up heat by evaporation. The vapor would be delivered to heat sinks, yielding heat by condensation. Compared to circulating liquid systems, mass flow rates and liquid line sizes would be reduced, film coefficients 40 would be higher, and pump power would be eliminated.

Capillary pumped heat pipe systems are, of course, well known in the prior art both for ground based and for space applications. In 45 the prior art, also, J.T. Pogson et al. (U.S. patent No. 4,040,478) teach that it is known to provide heat pipe systems having separate evaporators and condensers connected for fluid communication therebetween by individual 50 liquid and vapor lines. However, they do not provide a teaching of a system with an equipment mounting panel construction having a sheet wick in the panel interposed between the liquid grooves and the vapor channels 55 therein such that a high capillary pressure for efficient fluid circulation in a heat pipe system is attainable.

There is a teaching by W.P. Peck (U.S. patent No. 3,803,688) of a heat pipe having an 60 integral "screen wick" between the liquid capillary grooves and the vapor space of the device. Although the construction has a superficial resemblance to the panel design of the present invention, Peck provides capillary 65 grooves for the required fluid circulation there-

along and the screen wick disclosed therein does not act as a capillary pumping means as in the present invention but merely serves a vapor venting function. In addition, unlike 70 Peck, the grooves of the present invention cover only a small fraction of the heat transfer surface, and the porous wicking which covers both the grooves and the remainder of the surface serves to draw liquid in a direction transverse to the groove axis to completely 75 wet the surface. Evaporation occurs at the meniscus at the liquid-vapor interface near the exposed surface of the porous wicking.

The present invention is directed to a thermal management system comprising a plurality of capillary-pumped panels arranged in parallel in a heat transfer circuit. Vapor passage 80 means and liquid passage means in each of said panels are in fluid communication with one another through a wick. Dedicated vapor lines connecting said vapor passage means of each panel with one another are provided for the circulation of vapor therebetween, and dedicated liquid lines connecting said liquid 85 passage means of each panel with one another are provided for the circulation of liquid therebetween with the circuit being charged with a heat pipe working fluid. The panels mount equipment in a heat transfer relationship therewith, with heat emitting equipment mounted on at least one of said panels, and heat removing equipment mounted on at least one other of said panels, whereby a heat 90 input into a number of said panels causes a vaporization of fluid from the wicks therein and the removal of heat from another of said panels causes a condensation of fluid therein such that a circulation of fluid by the capillary pumping of said wicks that serves to transport heat between widely spaced panels in 95 said circuit is provided.

The capillary-pumped equipment mounting panel for use in the thermal management system comprises first and second coextensive 100 plates sealed together, vapor passage means in said first plate, liquid passage means covered with a sheet wick in said second plate with said passages being in fluid communication with one another through said wick 110 means there are provided connecting said vapor passage means to a vapor line outside said panel and means connecting said liquid passage means to a liquid line outside said panel, with said liquid passage means and said wick being charged with a heat pipe fluid.

This invention is a thermal management system incorporating capillary-pumped panels using heat pipe principles such that a heat transport loop without moving parts is provided. 115 In this system, the capillary pumped panel means serve both as a heat emitting equipment mounting means and also as the fluid circulating pumping means. The panel means can function as either heat absorbers or heat 120 rejectors in the fluid circuit or loop. To mini-

imize viscous flow pressure loss, the interconnections between the panel means and the heat dissipating radiators of the system are by means of separate liquid and vapor tubes or lines.

The panel means comprise a pair of flat coextensive plates fastened one on the other. A network of liquid grooves is provided in the faying surface of one plate and the channels

10 and most of the plate surface are covered with a thin fine-pored sheet wick. A network of vapor channels is provided in the faying surface of the other plate and the two plates are joined together in a hermetic relationship.

15 Fluid communication between the liquid grooves and the vapor channels is through the sheet wick. Each panel of the system has manifolding joining the vapor channel network to the separate vapor lines and the liquid

20 groove network to the separate liquid lines of the heat transferring loops of the system. The vapor channel networks of the panels are connected to one another and the liquid groove networks of the panels are connected to one

25 another such that the panels are connected in parallel in the fluid circuit. Heat emitting equipment is mounted on the panel preferably on the side having the plate with the liquid groove network such that the heat input

30 evaporates the liquid on the surface of the sheet wick. The evaporated liquid passes into the vapor channels and is circulated through the vapor lines to a panel acting as a heat rejector. Vapor condensed in the rejector (con-

35 denser) panel is collected and returned by the capillary action of the sheet wicks in the heat source (evaporator) panels and is returned as a liquid through the liquid line to the panel from whence it was evaporated and the cycle

40 is repeated.

Advantages of the present invention will become apparent from the figures and specifications which follow.

For the purpose of illustrating the invention, 45 there is shown in the drawings the forms which are presently preferred; it should be understood, however, that the invention is not necessarily limited to the precise instrumentalities and arrangements here shown.

50 Fig. 1 is a side view partially in section of the capillary-pumped panel of the invention with instruments mounted on one side thereof;

Fig. 2 is an exploded view of the capillary-pumped panel of the invention;

Fig. 3 is a diagrammatic representation of the thermal management system of the invention; and

Fig. 4 is a diagrammatic representation of 60 the thermal management system of Fig. 3 indicating typical system parameters.

With reference now to the drawings, Figs. 1 and 2 show details of construction of the capillary-pumped panel 10 of the invention.

Panel 10 comprises first and second flat coex-

tensive plates, 12 and 14 respectively fastened together with a sheet wick 16 interposed therebetween. Plates 12 and 14 can be fabricated out of any suitable thermally conductive material such as aluminum or copper.

70 A network 18 of narrow grooves 20 is provided in the faying surface 22 of plate 12 to feed the sheet wick which covers the grooves and most of the plate surface. A network 24

75 of channels 26 is provided in the faying surface 28 of plate 14. Groove network 18 is in fluid communication by means of a suitable manifold or port means 29 with a liquid line 30 and the channel network 24 is in fluid

80 communication with a vapor line 32 by means of a suitable manifold or port means 34. Sheet wick 16 can be fabricated out of any suitable thin heat pipe wicking material, but a very thin feltmetal sheet having a very fine

85 pore size is preferred. When the panel 10 is assembled, the network 18 of liquid grooves is covered with the wick 16 and the faying surface 22 and 28 of the plates are bonded together or are otherwise hermetically sealed

90 together as by means of a weld 36 around the adjoining edges 38 and 40 of the plates. To assure a proper capillary action, the peripheral edge 42 of the sheet wick extends outwardly on all sides beyond the perimeter of the groove and channel networks.

It will be recognized that the various dimensional and design parameters of the panel 10 and of its associated equipment such as the liquid and vapor lines or tubing 30 and 32 will be governed by the environment of use and the temperature range within which the system will operate. Typically, however, the panel 10 will be less than about one-half inch (13mm) thick, the liquid grooves will be about 0.063 in (1.6 mm) wide and 0.063 in. (1.6 mm) deep and the groove network 18 will have a groove spacing of about 0.5 in. (13 mm).

Figure 3 illustrates diagrammatically panel 10 used in a heat transfer loop 50 of a heat

110 management system. In the representation of panel 10 therein the diagonal wavy line represents the sheet wick 16, the section labeled "L" represents the liquid groove network 18,

115 and the section labeled "V" represents the vapor channel network 24. Heat emitting equipment such as instruments 44, 46, and 48 whose temperatures it is desired to control are mounted on the surface 52 of the panel. To form the heat transfer loop 50, the panels

120 10 are arranged in parallel with the liquid lines 30 and the liquid groove networks 18 of the panels connected together and the vapor lines 32 and the vapor channel networks 24 of the panels connected together. The loop is connected in a heat exchange relationship with a radiator 54 and it can be connected to a heat exchanger 56 of another heat transfer loop 58.

The loop is readied for operation by installing an appropriate quantity of heat pipe work-

ing fluid, typically Freon, ammonia, or water (not shown), generally until the liquid channels and sheet wicks of the panels are saturated, and the loop is hermetically sealed in accordance with normal practice. Because of the provision of the network 18 of liquid grooves 20 in the panels the liquid flow path in the porous metal sheet wick 16 is shortened. The short flow path is desirable because the sheet wick must be kept thin to prevent nucleate boiling under high heat flux conditions ( $>2$  watts/cm $^2$ ), and the combination of small cross-sectional flow area and low wick permeability would otherwise result in excessive liquid pressure losses.

In operation, a heat input, such as from a heat emitting instrument, into a panel 10 causes an evaporation of liquid at the meniscus at the liquid-vapor interface near the exposed surface of its sheet wick 16. Vapor from the evaporated liquid passes from the vapor channel network 24 and from thence into vapor line 32 where it is conveyed to the panel associated with the radiator 54. If heat transfer loop 58 is in a heat extraction mode, vapor will also flow to the panel associated with heat exchanger 56. The condition in which heat transfer loop 58 is shut off and an instrument 46 is temporarily off such that its associated panel is acting as a cold sink is illustrated in Fig. 3. As indicated by arrows 60, vapor from the panel associated with heat emitting instrument 48 flows both to the panel associated with inactive instrument 46 and to the radiator 54 panel and vapor from the panel associated with instrument 44 flows to the panel associated with radiator 54. Vapor condensed in the panels associated with the radiator 54 and instrument 46 is pumped by the wick 16 in each of those panels through liquid line 30 to the panels associated with heat emitting instruments 44 and 48 where capillary action results in the saturation of the wicks of the panels. A continued heat input into the panels causes a vaporization of the liquid at the surface of the sheet wick and the cycle is repeated.

A diagrammatic representation of usual system parameters for a typical thermal management system for a very large space system having heat transport distances of up to 25 meters is shown in Fig. 4.

Although shown and described in what are believed to be the most practical and preferred embodiments, it is apparent that departures from the specific methods and designs described and shown will suggest themselves to those skilled in the art and may be made without departing from the spirit and scope of the invention. We, therefore, do not wish to restrict ourselves to the particular constructions described and illustrated, but desire to avail ourselves of all modifications that may fall within the scope of the appended claims.

## CLAIMS

1. A thermal management system comprising a plurality of capillary-pumped panels arranged in parallel in a heat transfer circuit, vapor passage means and liquid passage means in each of said panels in fluid communication with one another through a wick, dedicated vapor lines connecting said vapor passage means of each panel with one another for the circulation of vapor therebetween, dedicated liquid lines connecting said liquid passage means of each panel with one another for the circulation of liquid therebetween, said circuit being charged with a heat pipe working fluid, said panels mounting equipment in a heat transfer relationship therewith, heat emitting equipment mounted on at least one of said panels, heat removing equipment mounted on at least one other of said panels, whereby a heat input into a number of said panels causes a vaporization of fluid from the wicks therein and the removal of heat from another of said panels causes a condensation of fluid therein such that a circulation of fluid by the capillary pumping of said wicks that serves to transport heat between widely spaced panels in said circuit is provided.
2. The thermal management system defined in Claim 1 wherein the wick has isotropic porosity such that liquid is drawn transverse the axis of said liquid passage means on either end thereof to completely wet the wick exposed to said vapor passage means.
3. A capillary-pumped equipment mounting panel for use in a thermal management system comprising first and second coextensive plates, sealed together, vapor passage means in said first plate, liquid passage means covered with a sheet wick in said second plate, said passages being in fluid communication with one another through said wick, means connecting said vapor passage means to a vapor line outside said panel, means connecting said liquid passage means to a liquid line outside said panel, said liquid passage means and said wick being charged with a heat pipe fluid.
4. A mounting panel as claimed in claim 3 wherein said plates have a flat planar configuration.
5. A mounting panel as claimed in claim 3 or claim 4 wherein the vapor passage means is a vapor channel network of channels in the faying surface of the first plate and the liquid passage means is a network of liquid grooves in the faying surface of the second plate.
6. A mounting panel as claimed in any of claims 3 to 5 wherein said wick is a thin, fine-pore sheet wick providing a small temperature drop therethrough and a high capillary pressure difference.
7. A mounting panel as claimed in any of claims 3 to 6 wherein the vaporization of fluid from the wick is from the surface of the wick on the side of the vapor passage means.

8. A mounting panel as claimed in any of claims 3 to 7 wherein the vaporization of fluid from the wick occurs at the meniscus at the liquid-vapor interface near the vapor passage side of said wick.
9. A mounting panel as claimed in any of claims 3 to 8 wherein the liquid passage means is coextensive with the wick whereby the short liquid flow lengths result in a low wick pressure drop.
10. A mounting panel as claimed in any of claims 3 to 9 wherein the wick has isotropic porosity such that liquid is drawn transverse of the axis of said liquid passage means on either side thereof to completely wet the wick exposed to said vapor passage means.
11. A thermal management system substantially as herein described with reference to the accompanying drawings.
12. A mounting panel substantially as herein described with reference to the accompanying drawings.

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